CHAPTER 6

Organic Chemicals

INTRODUCTION

Both natural and xenobiotic (manmade) organic compounds abound in the universe. Many of these compounds are toxic to humans and animals. Gribble (1994) points out that numerous chlorinated compounds are naturally produced. These include organohalogens, numerous halogenated alcohols, ketones, carboxylic acids and amides, aldehydes, epoxides and alkenes. Many of these are produced by fungi and marine algae, as well as during volcanic action, forest fires and brush and vegetation burning. He indicates that nearly 100 different chlorinated, brominated and iodinated compounds have been found in an edible seaweed favored by Hawaiians.

Our environment has been greatly contaminated by toxic organic chemicals, primarily as a result of industrial discharges and uses of pesticides. Industrial and manufacturing enterprises produce a myriad of organic chemicals. It has been estimated that more than 5 million distinct organic compounds are registered.

Following World War II, pesticide and herbicide usage in agriculture increased dramatically and many of the compounds used were very persistent in the environment. Kuhn and Suflita (1989) indicate that in recent years, 17 pesticides have been found in groundwater in 23 states. In the 1960s, there was increased awareness of the potential harmful effects of many of these organic compounds on humans, fish and wildlife. Through soil, water, or air, many of those compounds enter the sewer system and end up in biosolids.

Biosolids can contain toxic organic chemicals, principally as discharges from industrial sources, but also from atmospheric deposition (Webber and Lesage, 1989; USEPA, 1990; Jones and Sewart, 1997). Today many manufacturers and producers of organic compounds pretreat their wastewater prior to discharging into the sewer system. When organic compounds enter the wastewater treatment system, they can undergo reductions or transformations prior to being deposits in biosolids that will be applied to land. For example, chlorinated aliphatic compounds can undergo reductive dechlorination, hydrolysis, dehydrochlorination and dihaloelimination

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(Ballapragada et al., 1998). The authors found that specific bacteria accomplished dechlorination of several chlorinated organic compounds.

Jones and Sewart (1997) speculated that the process of potential importance during wastewater treatment could involve (1) deposition of dioxins in the biosolids, (2) microbial degradation during digestion, (3) volatilization of the lower-chlorinated homologue groups and (4) possible formation of PCDD/F during the wastewater treatment by microbial mediated reactions. This chapter does not discuss the fate of organic compounds during wastewater treatment.

The data on organic compounds in sewage sludge and biosolids were presented in Chapter 2, Characteristics of Sewage Sludge and Biosolids.

The organic compounds of greatest concern are:

- Toxic chlorinated compounds
- Alkylphenol ethoxylates
- Volatile organic compounds (VOCs)
- Dioxin and dioxin-like compounds
- Phthalates
- Polycyclic aromatic hydrocarbons (PAHs)
- Pesticides

The chlorinated compounds of major concern are polychlorinated biphenyls (PCBs). It is estimated that since 1935, more than 60,000 metric tonnes have been produced in the U.S. PCBs are very persistent and bioaccumulate. PCBs in soils can be taken by plants (Strek and Weber, 1980; O'Conner et al., 1990).

Alkylphenol ethoxylates are nonionic surfactants. The main alkylophenols used are nonylphenol ethoxylates. Alkylphenol ethoxylates compounds can be microbially metabolized (Ahel et al., 1994). Nonylphenol ethoxylates are susceptible to photochemical degradation.

Some of the sources of several priority pollutants are shown below:

- PCBs — electrical capacitors and transformers, paints, plastics, insecticides
- Halogenated aliphatics — fire extinguishers, refrigerants, propellants, pesticides, solvents
- Phthalate esters — polyvinyl chloride and thermoplastics
- Ethers — solvents for polymer plastics
- Phenols — synthetic polymers, dyestuffs, pigments, pesticides, herbicides
- Polycyclic aromatic hydrocarbons — dyestuffs, pesticides, herbicides, motor fuels and oils
- Dioxins — herbicides, pulp bleaching, emissions from waste incinerators, textiles
- Nonylphenol ethoxylates (NPEs) — pulp and paper, plastics, household cleaning agents, pesticides and paint

Consideration must be given both to the risk from a pollutant and to the potential for exposure. Exposure is a function of the presence of the compound in the media in question — in this case biosolids — but also to its presence in other sources. In fact, many times, exposure from food, air and water may greatly outweigh any potential exposure from biosolids applied to land. Chaney et al. (1990) estimated the risk from PCBs in sewage sludge applied to soil. They concluded that since

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sewage sludges contained very low levels of PCBs, the estimated risk level to the Most Exposed Individuals (MEIs) was $<10^{-4}$; low sludge PCBs and low probability of MEIs are at $<10^{-7}$ lifetime risk.

Furthermore, since untreated sewage sludge is not permitted to be applied to agricultural land, the additional transformation to biosolids can significantly reduce the level of organics. Chlorinated organic compounds can be biodegraded during anaerobic digestion (Ballapragada et al., 1998). During composting many organics are biodegraded; heat drying will destroy or volatilize many organics; and alkaline treatment will also transform or destroy some. There have been numerous studies showing that composting biodegrades many toxic organic compounds (Rose and Mercer, 1968; Deever and White, 1978; Snell Environmental Group Inc., 1982; Epstein, 1997; Laine and Jorgensen, 1997; Cole, 1998; Potter et al., 1999).

When biosolids containing toxic organic compounds are applied to land, the compounds can undergo numerous transformations and reactions. These can affect their potential impact to humans, animals and the environment. The main impact on humans and animals is through the food chain and water intake. Jones and Sewart (1997) list four major pathways for organic contaminants transfer into humans.

- Biosolids to soil to root crops
- Biosolids to soil to above ground crops
- Biosolids to soil to livestock ingestion to milk and animal tissues
- Biosolids to soil to groundwater to drinking water

They indicate that there are possibly other unusual and relatively minor pathways, such as direct ingestion of soil containing biosolids.

The main objective of this chapter is to provide information on the fate and potential impact of organic compounds in biosolids when applied to soil. Several excellent sources of more detailed information include reviews by Jones and Sewart (1997); Alexander (1995); Chaney et al. (1996); Sawhney and Brown (1989); and the Final Report by the Water Environment Association of Ontario (2001) entitled Fate and Significance of Selected Contaminants in Sewage Biosolids Applied to Agricultural Land Through Literature Review and Consultation with Stakeholder Groups.

FATE OF TOXIC ORGANIC COMPOUNDS WHEN BIOSOLIDS ARE LAND APPLIED

Soils throughout the world are contaminated with toxic organic compounds. Soil contamination can result from atmospheric deposition, combustion of wastes, waste disposal, spillage of industrial materials, usage of pesticides, discharges of household chemicals and numerous other ways. For example, atmospheric deposition is the primary means of soil contamination of PCDD/Fs, according to Jones and Sewart (1997). They reported that soils in urban and industrial areas had higher concentrations than rural soils.

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Table 6.1 Level of Selected Toxic Organic Compounds in Rural North American Soils

Compound	Number of Samples	Geometric Mean g Mg^{-1}	Standard Deviation
PCDD/Fs*	70	0.46 ¥ 10^{-6}	5.1
PCBs	1,483	0.007	2.7
PAHs	>24	0.06	4.3

* The authors quantified PCDD/Fs in terms of I-TEQ values that were estimated from published homologue and congener data.

Source: Cook and Beyea, 1998, *Toxicol. Environ. Chem*. 67: 27–69. With permission.

Table 6.2 Estimated Atmospheric Deposition of Selected Toxic Organic Compounds

Compound	Number of Locations	Mean g ha^{-1} yr^{-1}
PCDD/Fs*	>4	16 ¥ 10^{-6}
PCBs	9	0.1
PAHs	6	3.5

* The authors quantified PCDD/Fs in terms of I-TEQ values that were estimated from published homologue and congener data.

Source: Cook and Beyea, 1998, *Toxicol. Environ. Chem*. 67: 27–69. With permission.

No systematic survey of dioxin soil levels has been conducted in the United States (USEPA, 1999). Based on the examination of data from numerous projects, USEPA reported that, for rural soils, the values ranged from one to six ppt I-TEQ (International Toxic Equivalents). In Table 6.1, Cook and Beyea (1998) showed levels of several organic compounds in rural North American soils.

Cook and Beyea (1998) also published data on atmospheric deposition of selected organic compounds (see Table 6.2) and time constants for the disappearance of these compounds (see Table 6.3). Apparently, these compounds are very persistent in soils.

When biosolids are land applied, toxic organic compounds can undergo numerous reactions and transformations. These can affect their movement through the soil to water resources, uptake by plants, volatilization to the atmosphere, accumulation in soil biota and other fates. The major reactions, transformations and fate in the soil are:

- Volatilization and wind erosion
- Photodecomposition or photochemical degradation
- Foliar interception and adsorption
- Plant uptake and crop removal
- Runoff and erosion to surface waters
- Soil adsorption and desorption
- Leaching to groundwater
- Biological degradation
- Chemical decomposition
- Uptake by soil biota

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Table 6.3 Time Constants for the Disappearance of Selected Toxic Organic Compounds from Soils Treated with Biosolids

Compound	Number of Years of the Study	% Loss	Estimated Number of Years for Disappearance	Reference
PCDD/Fs	22	26–50	>100	McLachlan et al. (1996)
PCBs	0.66	8–33	2.5–5.9	Fairbanks et al. (1987)
	30	91	14–19	Alcock et al. (1996)
PAHs	30	39-45	30	Wild et al. (1990)
	21	ca. 90	9	Wild et al. (1991)

In a review entitled "How Toxic Are Chemicals in Soil?" Alexander (1995) indicates that the hazard and risk from toxic chemicals diminish as the compounds persist in soil. Many of the reactions and transformations are responsible for the diminishing of organic chemicals.

Most of the scientific literature dealing with persistence and fate of organic chemicals pertained to pesticides. However, in recent years, considerable focus has been given to the chlorinated compounds. These compounds are often very persistent and remain in soils for long periods of time. The half-life of PCDD/Fs in surface soils may be on the order of 10 years or more (Alcock et al., 1996). USEPA indicates that there is no systematic survey of dioxin soil levels in the United States (USEPA, 1999). Rural soils values generally range from 1 to 6 ppt I-TEQ (International Toxic Equivalents) and urban soil values range from seven to 20 I-TEQ.

Volatilization

Volatilization of organic compounds from soil can be very significant. An organic compound in biosolids, spread on the surface or incorporated into the soil, will partition between the gas and liquid phases to exert a vapor pressure. This vapor may be rapidly lost. Many aromatics, such as toluene, benzene, cyclohexane and others, are volatile. Increasing the organic matter level of soil tends to decrease the volatilization of the hydrophobic nonpolar aromatics.

Fairbanks et al. (1987) reported that in an unamended soil, volatilization of PCBs ranged from 5% to 31%. Volatilization of organics was the major means of loss of ^{14}C in unamended soil. The addition of biosolids decreased the rate of volatilization and environmental transport. They indicated that sewage sludge can decrease plant uptake of PCB since foliar contamination from vapor sorption is the primary source of PCB contamination of some plants. Furthermore, the addition of sewage sludge increased the complete degradation or detoxification of PCBs.

Jin and O'Conner (1990) found in a laboratory study that more than 80% of toluene was volatilized from either unamended or sludge-amended soils. They indicated that volatilization is a major force in toluene movement. Therefore, to reduce possible groundwater and air pollution by toluene due to sludge application, the sludge should be incorporated into the surface layer or deeper.

Wilson and Jones (1999) reported that volatilization was the predominant loss process for volatile organic compounds (VOCs) from land application of biosolids.

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The rate of loss depended on biosolids' application rate, method of application, soil properties and compound characteristics. When biosolids are applied to land, the loss of VOCs, PCBs and chlorophenols (CPs) by volatilization can be important (Wilson et al., 1997). Dioxins and furans may be volatilized and adsorbed by foliage. Carpenter (2000) indicates that the half-lives for PCDD/Fs range from 10 to 17 years, but when residues are on the surface the half-life is considerably shorter. This is probably due to both volatilization and photo-oxidation.

Photodecomposition

There is virtually no data on photodecomposition of organic compounds from surface-applied biosolids. Some organic compounds in biosolids applied to the soil surface can undergo photodecomposition. Phenolics and polynuclear compounds can undergo such reactions when exposed to solar radiation. Usually photodecomposition is measured as part of the total decomposition by biological and abiotic mechanisms.

Degradation

Many bacteria, fungi and other organisms have been found to degrade organic compounds under aerobic conditions. For example, Saber and Crawford (1985) isolated strains of *Flavobacterium* that degraded pentachlorophenol (PCP). The white rot fungi have been found to degrade a wide host of organic compounds. Barr and Aust (1994) listed the environmental pollutants degraded by the white rot fungus *Phanerochaete chrysosporium*. These include:

- Chlorinated aromatic compounds
  - Pentachlorophenol (PCP)
  - 2,4,5-Trichlorophenoxyacetic acid
  - Polychlorinated biphenyls (PCB)
  - Dioxin

- Polycyclic aromatic compounds
  - Benzo(a)pyrene
  - Pyrene
  - Anthracene
  - Chrysene

- Pesticides
  - 1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane (DDT)
  - Lindane
  - Chlordane
  - Toxaphene

Many organic compounds will degrade in the soil. This process is extremely important as a means of removing several toxic organic compounds. There is extensive literature on the degradation of pesticides in soil. Organic matter can either

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accelerate or possibly inhibit biodegradation. Guthrie and Pfaender (1998) determined that biodegradation was the main means of removing pyrene. Accelerated biodegradation could occur through the enhancement of the microbial population and its activity. Organic matter can also tie up compounds, thus reducing or delaying their assimilation by the microbial population. Adding compost to soils accelerates the degradation of toxic organic compounds. Stegmann et al. (1991), Atlas (1991), and Hupe et al. (1996) showed that compost added to soils was effective in hydrocarbon degradation.

Bellin et al. (1990) studied the degradation of pentachlorophenol (PCP) in biosolids-amended soils. Pentachlorophenol is highly toxic. It has been used primarily as a fungicide and insecticide in the preservation of wood. Extensive use of this compound has resulted in contamination of soils, water, air and biosolids (Buhler et al., 1973). DNP or 2,4-dinitrophenol is a compound toxic to animals and plants that occurs as a waste contaminant from several industrial sources (O'Conner et al., 1990). The authors found that it was rapidly degraded in soils and only slightly affected by biosolids. Degradation of PCP appeared to be more favorable in high-pH soils. Their data for the Norfolk soil suggested a first-order degradation with a half-life of about 38 days. Wilson et al. (1997) indicated that biodegradation was a very important process in the loss of toluene and *o*-, *m*- and *p*-xylene, PCBs and PCPs in soil. This was not true of PCDDs/Fs.

Nonylphenol ethoxylates (NPEs) are found in soils where biosolids have been applied. Marcomini et al. (1989) evaluated the fate of various NPEs in sludge-amended soil. They determined that 80% of NPEs in the sludge-amended soil degraded in the first month. There remained residual levels after 320 days. Possibly, some of the NPEs may have leached out of the analytical zone. NPE does not appear to significantly move through soils to groundwater (Langenkamp and Part, 2001).

Fairbanks and O'Connor (1982) showed that 84% to 89% of di (2-ethylhexyl) phthalate (DEHP) was degraded in 146 days. Overcash (1983) indicated that the decomposition half-life for di-*n*-butylphalate ester was approximately 80 to 180 days and for nonionic surfactants, 300 to 600 days.

Kuhnt (1993) reported that surfactants used in domestic detergents such as LAS and non-ionic LAE are rapidly and extensively degraded in biosolids-amended soil and even in soils with no previous exposure to those compounds. Managas et al. (1998) also reported complete loss of LAS from biosolids-amended soil within 98 to 336 days. Under aerobic conditions, LAS has been reported to degrade rapidly (Litz et al., 1987; Madsen et al., 1997). Jensen (1999) concluded that the combination of relatively rapid aerobic degradation and reduced bioavailability when biosolids are applied likely prevents LAS from posing a threat to terrestrial ecosystems on a long-term basis.

PLANT UPTAKE OF ORGANIC COMPOUNDS

The potential plant uptake of toxic organic compounds from biosolids-amended soils depends on (a) the presence of the compound and its concentration in the biosolids; (b) the chemical and physical properties of the compound; (c) reactions

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in the soil that affect its availability and (d) rate of uptake by plants. Simonich and Hites (1995) determined that environmental factors and plant species are also important factors. As was indicated in Chapter 2, biosolids generally contain very low levels of toxic organic compounds. The principal concern has been with low levels of highly persistent and toxic compounds such as PCBs, PAHs, dioxin, PCPs, phthalates and similar compounds.

Bioconcentration factors (BCFs) are used to quantify plant contamination. Organic chemicals can enter the plant from a contaminated soil and be translocated in the plant through the xylem. The compound needs to be soluble, since the xylem transports water from the roots to the leaves by transpiration. Organic compounds can also enter through the leaves from the atmosphere and be translocated by the phloem. These pathways are a function of (a) the chemical and physical nature of the compound, such as lipophilicity and water solubility; (b) environmental factors such as ambient temperature; (c) edaphic factors such as organic content of the soil; and (d) plant species (Simonich and Hites, 1995).

Early data demonstrated that several organochlorine pesticides are adsorbed by root crops (Lichtenstein, 1959; Lichtenstein and Schulz, 1965; Harris and Sans, 1967; Beall and Nash, 1971). Iwata and Gunther (1976) reported that carrot roots absorbed PCBs. However, 97% of the PCBs were found in the peel, with very little translocated in the plant tissue.

Studies on PCB uptake from biosolids-amended soils are limited. Davis et al. (1981) showed that with Milorganite, a heat-dried biosolids product containing low concentrations of PCBs (20 to 40 mg/kg), there was no detectable PCB in grass. O'Connor et al. (1990) studied the uptake of PCBs by fescue, carrot and lettuce from a highly contaminated sludge. The sludge contained 52 mg/kg of PCBs. Only carrots were contaminated, though the PCB contamination was restricted to the peel. The concentration of PCBs in this study was considerably higher than concentrations of one to five mg/kg typically found in biosolids.

Ingestion by animals of plants and accumulation in animal byproducts, represent another mechanism for a toxic organic compound to enter the food chain. Extensive studies were done on PCB intake to tissue and milk in dairy cattle (Fries et al., 1973; Willet, 1975). They showed that Aroclor 1254 was concentrated in milk fat.

Fries (1982) cites three means of plant contamination: direct, indirect and soil ingestion by animals. Direct plant contamination occurs when biosolids are applied to a crop and adheres to plant surfaces. In the case of liquid sludge application to forage crops, the PCB intake by animals will depend on whether they are allowed to graze shortly after application. Currently, the 503 regulations require a waiting period of 30 days prior to grazing. However, if the forage is mowed and fed to animals, some of the biosolids would adhere to the crop. Indirect intake by animals depends on the root adsorption and translocation to the foliage. As indicated earlier, scientific evidence shows that PCBs are not taken up by most plant roots and translocated to the aboveground portions of plants. Grazing animals will ingest soil. Fries (1982) found that grazing dairy cattle's ingested soil represents as much as 14% of their dry-matter diet. Thus, biosolids containing toxic organics, when left on the soil surface, can be ingested along with the soil. Incorporating biosolids into the soil is the best way to reduce animal exposure.

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PAHs are ubiquitous and are found in soils and foliage due to atmospheric deposition (Wild and Jones, 1992). Plant uptake through the roots is limited since organic matter adsorbs them. The organic matter in biosolids increases the adsorption potential, thus making them less available to plants (Ryan et al., 1988). Furthermore, since PAHs are lipophilic/hydrophobic compounds, they tend to be more greatly adsorbed by soil organic matter.

Wild and Jones (1992) suggest that root uptake may be enhanced by the presence of surfactants in biosolids and that adsorption onto root surfaces can be an important process in root uptake. They analyzed carrot foliage, root peels and root cores for 15 PAHs. Neither foliage nor root cores were affected by anaerobically digested biosolids. Carrot root peel PAH concentrations increased to a plateau with increasing soil PAH levels.

Pentachlorophenol (PCP), the compound used as a wood preservative, has contaminated water, air, food and sediment over the years (Bevenue and Beckman, 1967; Buhler et al., 1973). Bellin and O'Connor (1990) evaluated the uptake of PCP by tall fescue, lettuce, carrot and chili pepper from biosolids-amended soil. They found minimal plant uptake of intact PCP in fescue and lettuce and none in carrot or chile plants. Plant dry wt/initial soil concentration (BCF values) for the lettuce and fescue were <0.01. They found that degradation in the soil was rapid and that minimal contamination could occur in the field.

Chlorobenzenes (CBs) can be found in biosolids. They are lipophilic and volatile and therefore can be taken up by both the roots and foliage (USEPA, 1985). Overcash et al. (1986) indicated that monochlorobenzene and 1,4-dichlorobenzene reached the highest BCFs into crops grown on sludge-amended soil. Wang and Jones (1994) studied the uptake of CBs by carrots grown in soil treated with different rates of sewage sludge. Both carrot foliage and roots took up CBs from all the soil treatments. There was no evidence that the CBs were translocated from the roots to the tops. There was some penetration by dichlorobenzene from the peel to the core.

Phthalates are found in sludge and biosolids. The most common compound is di-(2-ethylhexyl) phthalate (DEHP). Studies prior to 1990 investigated the uptake of DEHP from soil (Overcash et al., 1986). DEHP is strongly adsorbed to the soil organic matter; therefore the presence of biosolids may decrease DEHP availability and reduce uptake by plants (Aranda et al., 1989). The authors studied the uptake of DEHP from sludge-amended soil by three food chain crops — lettuce, carrot and chili pepper — as well as tall fescue. Intact DEHP was not detected in any of the plants. The low bioconcentration factors suggested very little uptake of DEHP.

Since dioxins are considered highly toxic and are ubiquitous as a result of atmospheric deposition, recent attention has been focused on potential uptake by plants (Hülster et al., 1994; Welsch-Pausch et al., 1995). Jones and Sewart (1997) reviewed the uptake of PCDD/F by plants and the various pathways. They state that PCDD/F concentration in the aboveground portion of plants is controlled by foliar uptake and is virtually unaffected by changes in soil concentrations. Jones and Sewart (1997) and Wild et al. (1994) conclude that the influence of biosolids' application on PCDD/F concentration on aboveground plant tissues can be ignored in the pathway analysis.

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Table 6.4 Examples of Organic Compounds and the Organisms That Degrade Them Under Aerobic Conditions

Organic Compound	Organism	Environment
2-Chlorobenzoic acid	*Pseudomonas*	Aerobic, Soil
4-Chlorobenzoic acid	*Arthobacter*	Aerobic
3,5-Dichlorobenzoic acid	*Pseudomonas*	Aerobic
3-Chlorobenzene	*Pseudomonas*	Aerobic
1,4-Dichlorobenzene	*Pseudomonas*	Aerobic
1,4-Dichlorobenzene chlorobenzene	*Alcaligenes*	Aerobic
3-Chlorophenol	*Nocardia*	Aerobic
4-Chlorophenol	*Mycobacterium* *Alcaligenes* *Flavobacter*	Aerobic
Pentachlorophenol (PCP)	*Arthrobacter* *Flavobacter* *Pseudomonas* *Coryneform*	Soil Aerobic Aerobic Aerobic
2,4-Dichlorophenoxyacetic acid (2,4-D)	*Pseudomonas* *Azobacter*	Soil Aerobic
2,4,5-Trichlorophenoxacetic acid (2,4,5-T)	*Pseudomonas*	Soil
1,1,1-Trichloro-2,2-bis(*p*-chlorophenol)ethane (DDT)	*Escherica* *Pseudomonas* *Aerobacter* *Clostridium* *Proteus* *Fusarium* *Mucor* *Cylindrotheca* *Nocardia* *Streptomycetes* *Phanerochaete*	Aerobic
Polychlorobiphenyl (PCB)	*Alcaligenes* *Acintobacter* *Pseudomonas*	Aerobic, soil Aerobic Soil

Source: Boyle, 1989, *J. Environ. Qual*. 18(4): 395–402. With permission.

Hülster et al. (1994) reported that the fruits of zucchini had higher concentrations of PCDD/PCDF than other fruits and vegetables. They indicated that uptake by zucchini and pumpkin was principally from the roots with subsequent translocation to the shoots and fruit. However, as Jones and Sewart (1997) indicate, these crops make up a very small amount of our diet and therefore are not very significant as a human exposure pathway.

Cucumber plants were mainly contaminated by atmospheric deposition. In a study with Welsh ray grass, an important food chain plant, Welsch-Pausch et al. (1995) did not find that soil-related uptake was important in plant uptake of PCDD/PCDFs. Dry gaseous deposition was the principal pathway of contamination.

Table 6.4 presents some examples of organic compounds and organisms that degrade them under aerobic conditions. Thus, over time, many of the persistent organic compounds will biodegrade in the soil.

O'Connor (1998) found three factors that reduce the potential for plant contamination: low concentration of toxic organic compounds in biosolids-amended soil;

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strong adsorption of toxic organics to soil or biosolids; and loss of toxic organics from soil through degradation.

Thus, O'Connor (1998) and Chaney et al. (1996) concluded that the potential uptake of biosolids–borne and compost-borne toxic organics is small. Furthermore, toxic organic compounds are very large molecules; therefore, with the exception of some root crops, they are not taken up by plants and translocated to the edible portion. Also, toxic organics may be metabolized within the plant. Jacobs et al. (1987) did not find any phytotoxic effects of organic pollutants when biosolids were land applied.

CONCLUSION

Both natural and xenobiotic (manmade) organic compounds abound in the universe. Many of these compounds are toxic to humans and animals. When organic compounds in biosolids are land applied, they may undergo numerous reactions and transformations in the soil. Surface application of biosolids can result in volatilization and photochemical degradation. In the soil the compounds may be chemically decomposed, adsorbed on soil particles, biodegraded, or move through the soil. Plant uptake of organic chemicals is minimal.

Foliar interception and adsorption can also occur primarily from atmospheric deposition. Soil biota may take up organic chemicals. Soil erosion and runoff can contaminate water courses. The relative risk from organic chemicals in biosolids has been shown to be minimal as a result of their relative low levels and their many transformations, especially biological degradation.

The Water Environment Association of Ontario 2001 in its final report entitled, "Fate and Significance of Selected Contaminants in Sewage Biosolids Applied to Agricultural Land Through Literature Review and Consultation with Stakeholder Groups" provided a synopsis of the properties, occurrence, fate and transfer of the principal organic contaminant groups found in sludge and biosolids. The information was based on a paper by Smith (1996).

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